Lead-free Electronics in Aerospace Systems

Parts Standardization and Management Committee

November 16. 2006

Boeing Phantom Works

Situation

Reduction of Hazardous Substances (RoHS)

- EU Directive banning "placing on market" new electronic equipment containing specific levels of certain hazardous materials, including lead
- Commercial electronics industry has nearly completed the transition

Waste Electrical and Electronic Equipment Directive (WEEE)

- EU directive aims to minimize the impact of electronic waste
- Encourages and sets criteria for collection, treatment, recycling
- Makes the *producer responsible*
- Implemented by legislation in EU, China, and some US States

Legal situation

- Aerospace is currently either out of scope or excluded from directives
- "Gray areas" exist (in-flight entertainment, commercial items such as disk drives, etc.)
- Exemptions requested by US and European aerospace and military organizations

Practical situation

Aerospace will be "swept along" by a supply chain

Impact on Military and Aerospace Systems

Military and Aerospace systems have unique issues

1. Rugged operating environments
2. Long service life
3. High consequences of failure
4. We still *repair* boards

Programs in various stages of the transition

- Products that have been designed and qualified with traditional lead-based electronics (components, materials, and assembly processes), and remain lead-based
- Products that have been designed and qualified with traditional tin-lead electronic components, and have evolved to include lead-free electronics
- Products designed as lead-based, and transitioning to lead-free solder
- Products newly designed with lead-free solder

Commercial lead-free solutions may not apply to Military and Aerospace applications

There is no Drop-in Replacement

Reflow Soldering

Material	EU	Japan
Sn-Ag-Cu	64%	61%
Sn-Ag	8	9
Sn-Bi	4	0
Sn-Ag-Cu-Bi	-	5
Sn-Zn-Bi	-	9
Sn-Cu	-	1
Others	4	-
Don't know	20	15

Wave Soldering

Material	EU	Japan
Sn-Ag-Cu	42%	64%
Sn-Ag	17	20
Sn-Bi	8	5
Sn-Ag-Cu-Bi	4	-
Sn-Zn-Bi	-	2
Sn-Cu	-	1
Others	4	8
Don't know	25	-

Component Leads

Material	US	Japan	EU
Pure Sn	39%	30%	26%
Pd-Au	1	4	15
Au-Ni	6	-	13
Sn-Ag-Cu	13	9	10
Sn-Ag	3	3	8
Sn-Bi	10	14	5
Sn-Cu	5	21	5
Ag	-	4	5
Don't know	-	-	13
Au	5	8	-
Sn-Ag-Cu-Bi	-	2	-
Ni-Pd	1	1	-
Sn-Zn-Bi	-	1	-
Ni-Pd-Au	8	-	-
Sn-Pb	5	-	-
Others	4	3	-

EU: Survey responses from 52 organizations

Japan: 95 assemblers and 100 suppliers

US: 71 suppliers

Sources (summarized by CALCE, U of MD):

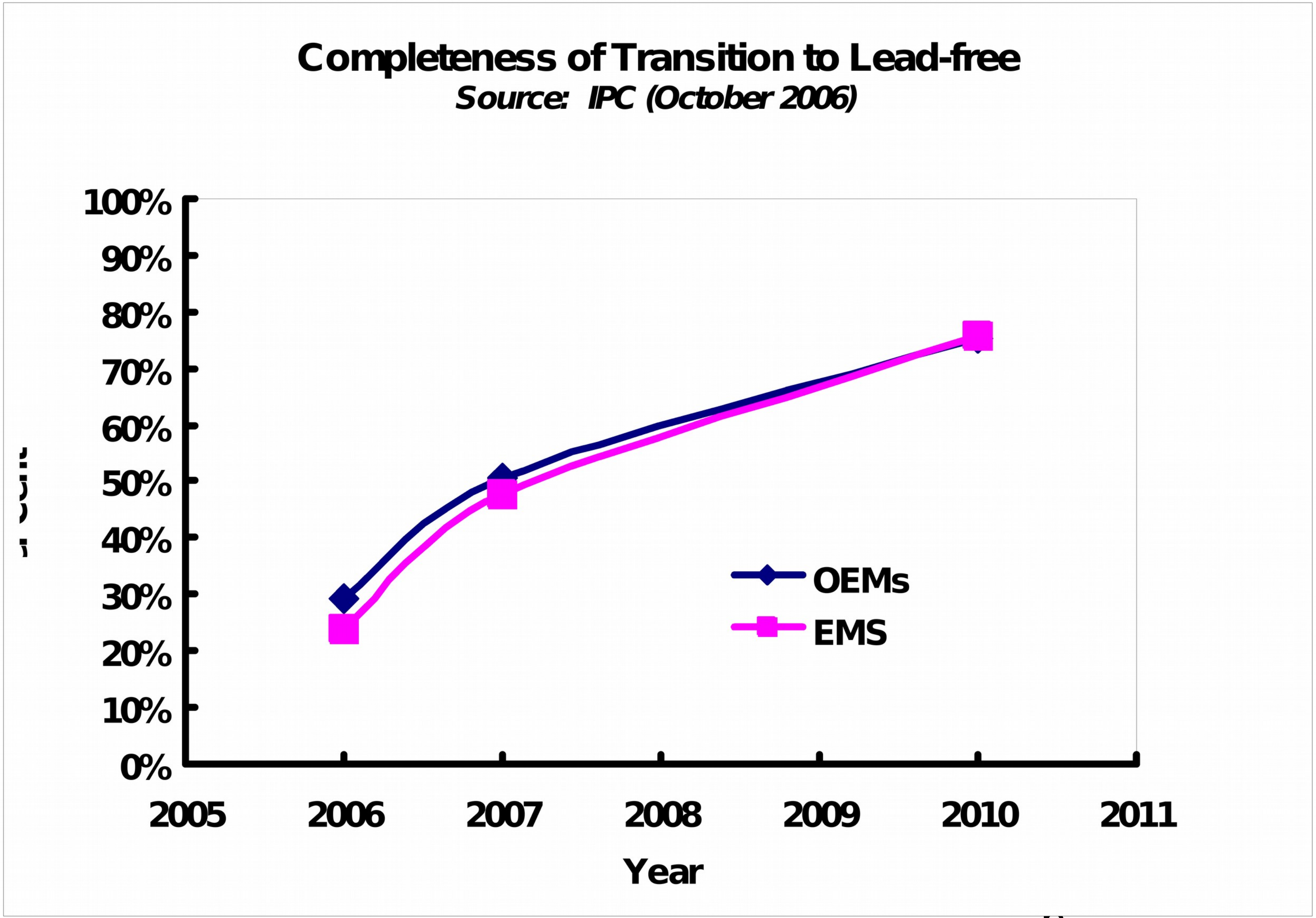
- Japan Engineering and Information Technology Assocation Tech. Rep. "Result and Analysis of Pb-free Survey," pp. 157-171, 2002
- Soldertech at Tin Technology 2nd European Roadmap, 2003

Aerospace Has Limited Influence on the Electronics Supply Chain

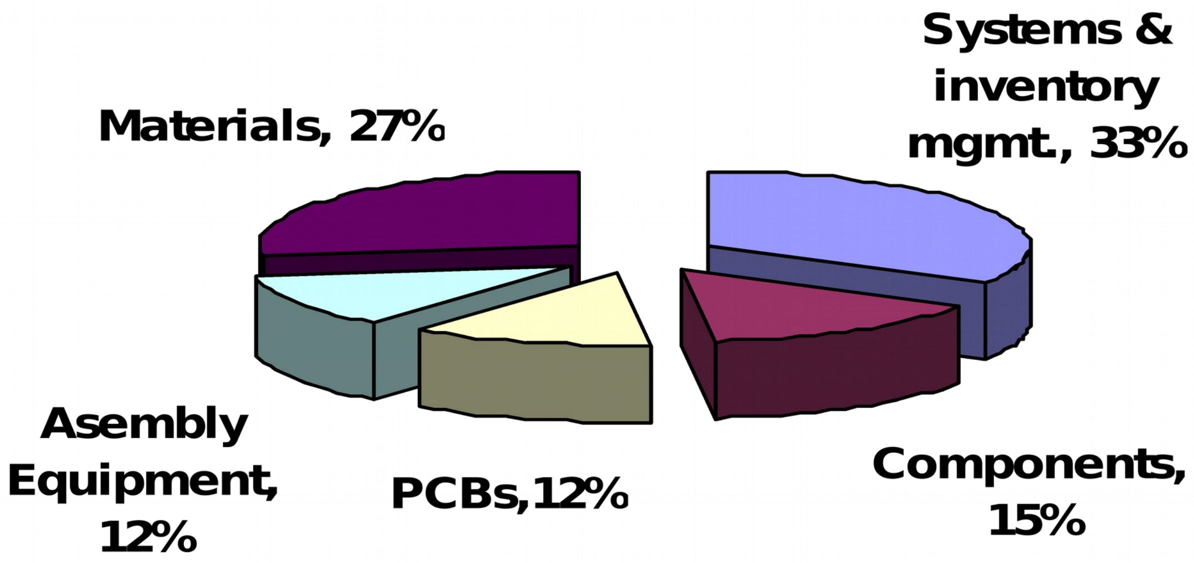
Electronics Market Sector	Total Market, 2004 ($B)	Market Share, 2004 (%)
Consumer	12.9	14.7
Computers	28.4	32.3
Telecomm.	36.4	41.4
Automotive	5.1	5.8
Industrial	4.1	4.6
Mil/space	0.97	1.1

We must design, produce, and support cost-effective aerospace products with electronics designed for other industries

Progress in the Transition



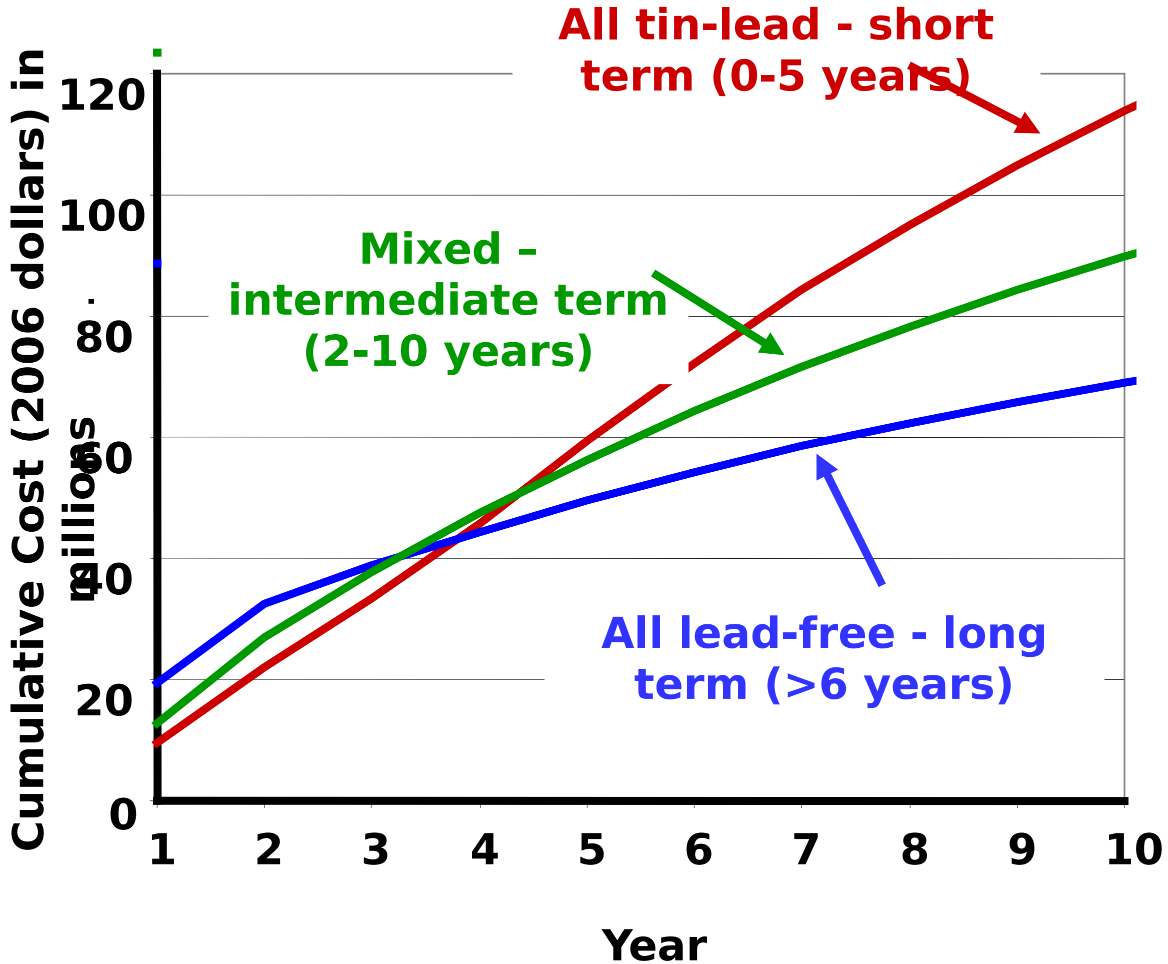
Greatest Cost in Implementation - OEMs



Source: IPC, October 2006

Costs

Cost to a typical BCA electronics supplier over ten years *(Source: Professor Peter Sandborn, U of MD)*



Cost includes recurring and non-recurring

- 24 'generic' PWA part numbers
- 300 parts/PWA
- Annual volume of 1000 PWA/part no.

(100 Avionics OEMs) x ($100M) = $5B over 10 years

Unique* Military and Aerospace Risks

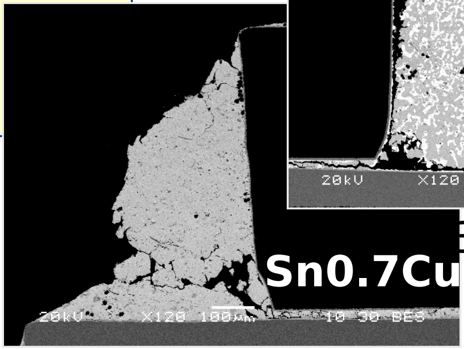
1. **Reliability**
2. **Configuration Control**
3. **Limitations on Use**
4. **Tin Whiskers**
5. **Repair and Maintenance**

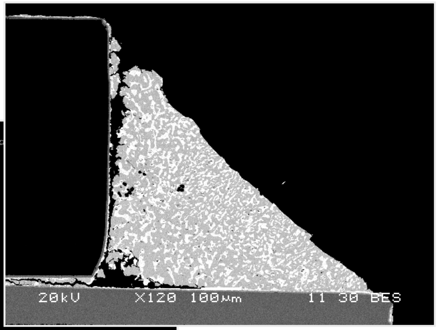
Unique in the sense that solutions used by other industries are not likely to be adequate for military and aerospace systems

Reliability

Solder may enter the system through:

- Component termination material or finish
- Printed wiring board pad material
- Assembly alloy
- Initial production or repair





3196 cycles

Risks:

- Solder joint cracks due to different material structures and properties
- Weak solder joints due to voids or brittle intermetallic formation
- Weak solder joints due to mixing of incompatible materials in production or repair
- Greater CTE mismatches due to higher reflow temperatures
- Failures due to more aggressive fluxes and cleaning solutions

An Acceptable Response?

"I'm going to stay with lead-tin as an assembly alloy, so I don't have to change anything."

By itself, this is not an acceptable response, because the program, or the avionics OEM, will almost certainly receive components with lead free termination finishes, or solder balls, or other termination materials. They also may receive printed wiring boards with lead-free finishes. These components or PWBs may either be used as-is (mixed technology) or re-processed.

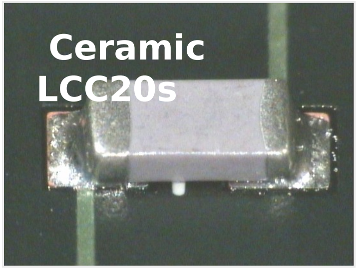
If lead free materials are received, the following questions must be answered:

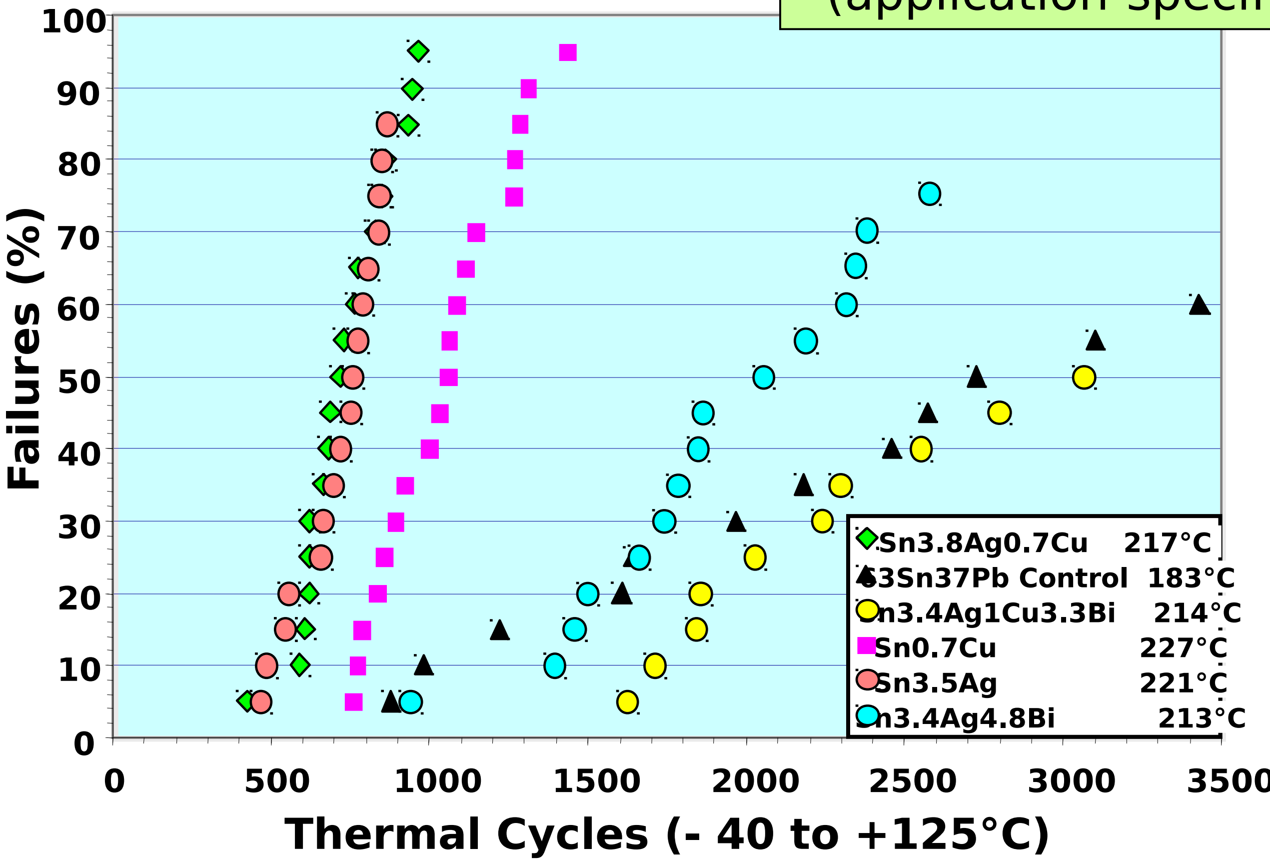
1. Will the lead free alloy be removed or replaced?
2. What is the documented process for identifying the lead free material?
3. What is the documented process for removing the lead free material?
4. What is the documented process for replacing the lead free material?
5. Does the part manufacturer warrant the part after re-processing?
6. What is the impact of the re-processing on the reliability of the

eliability Assessment is Complex

There is no consensus reliability assessment method for high performance electronics

No alloy is inherently “reliable” or “unreliable” (application-specific)





Conflicting results from different:

- Test methods
- Component types
- Location on board

Configuration Control

Potential issues

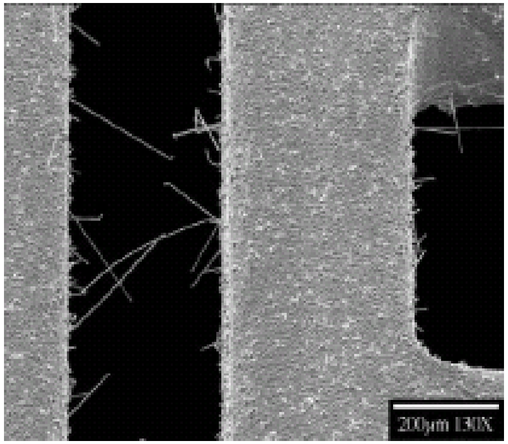
- Component termination material changed by component manufacturer during avionics system production cycle
- Component used for repair has different termination material than that of the original
- Different materials on the same assembly

The repair shop must know the alloys it is dealing with

Limitations on Use

- **System Reliability Methods Can Vary According to Application**
  - **Ground, atmosphere, space**
  - **Commercial vs. military**
  - **Critical vs. non-critical**
  - **Location in/on the vehicle**
  - **Maintenance and repair processes/practices**
- **Some solder alloys are incompatible with each other**
  - **Bismuth and lead**
- **Temperature limitations**
  - **Reflow temperatures can vary (PbSn- 183°C, SnAgCu - 217°C)**
  - **Tin pest is possible at low temperatures**

Tin Whiskers



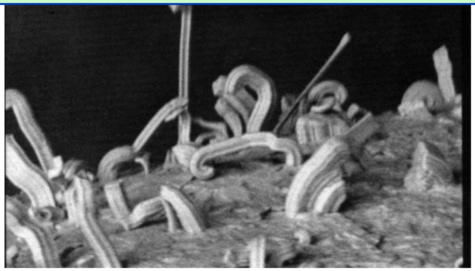
Tin whisker effects documented since 1940's

- "Grow" from nearly all tin alloys
- Lengths of a few microns to over 1mm
- Electrically conductive
- Single crystal
- Minimally predictable or controllable

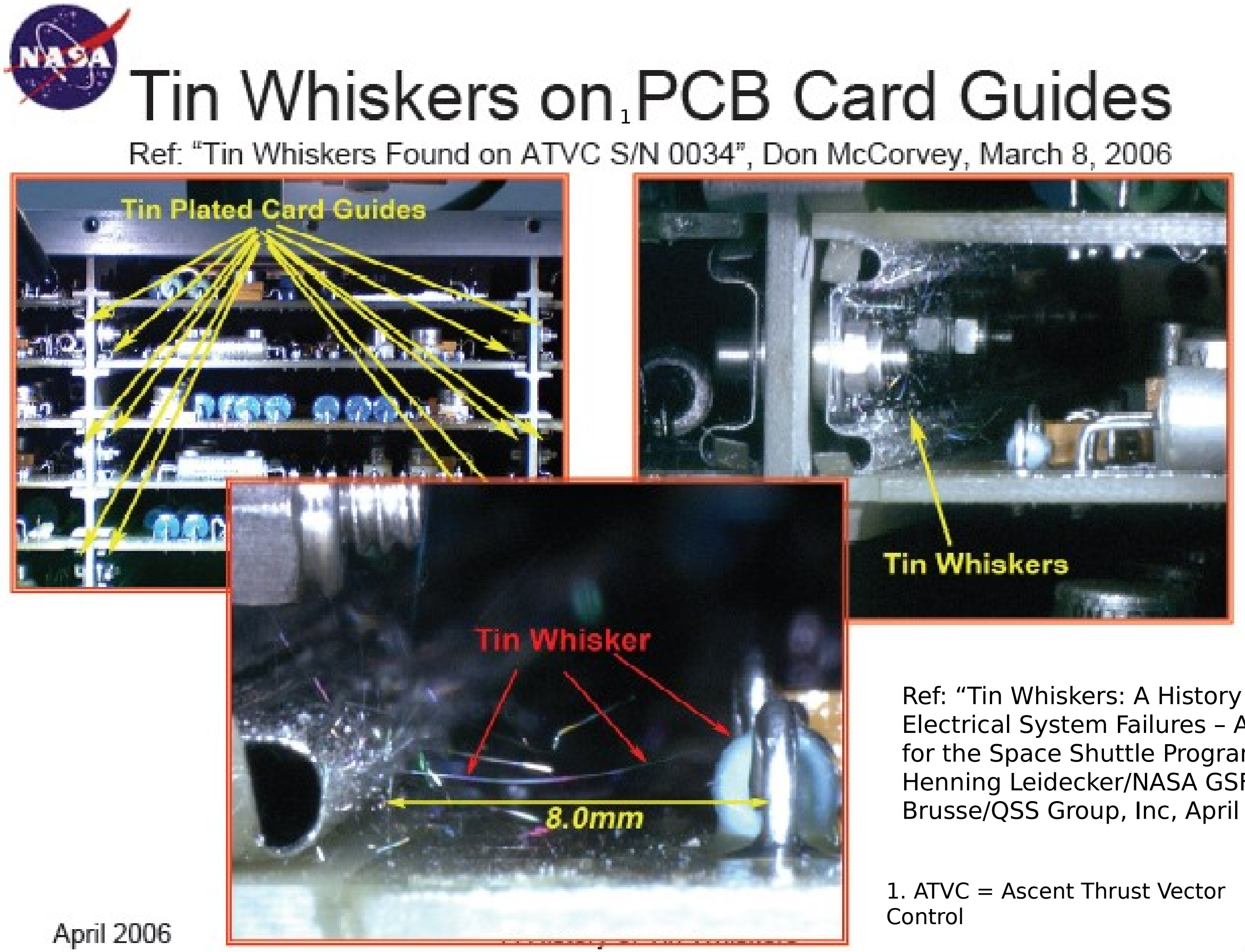
Whisker induced failures:

- *Short Circuit* – bridges two adjacent pins
- *Metal vapor arc* – high voltage causes plasma arc
- *Contamination* – whisker breaks off

Photo Courtesy of NASA Goddard Space Flight Center
http://nepp.nasa.gov/whisker



Tin Whiskers Found in Space Shuttle

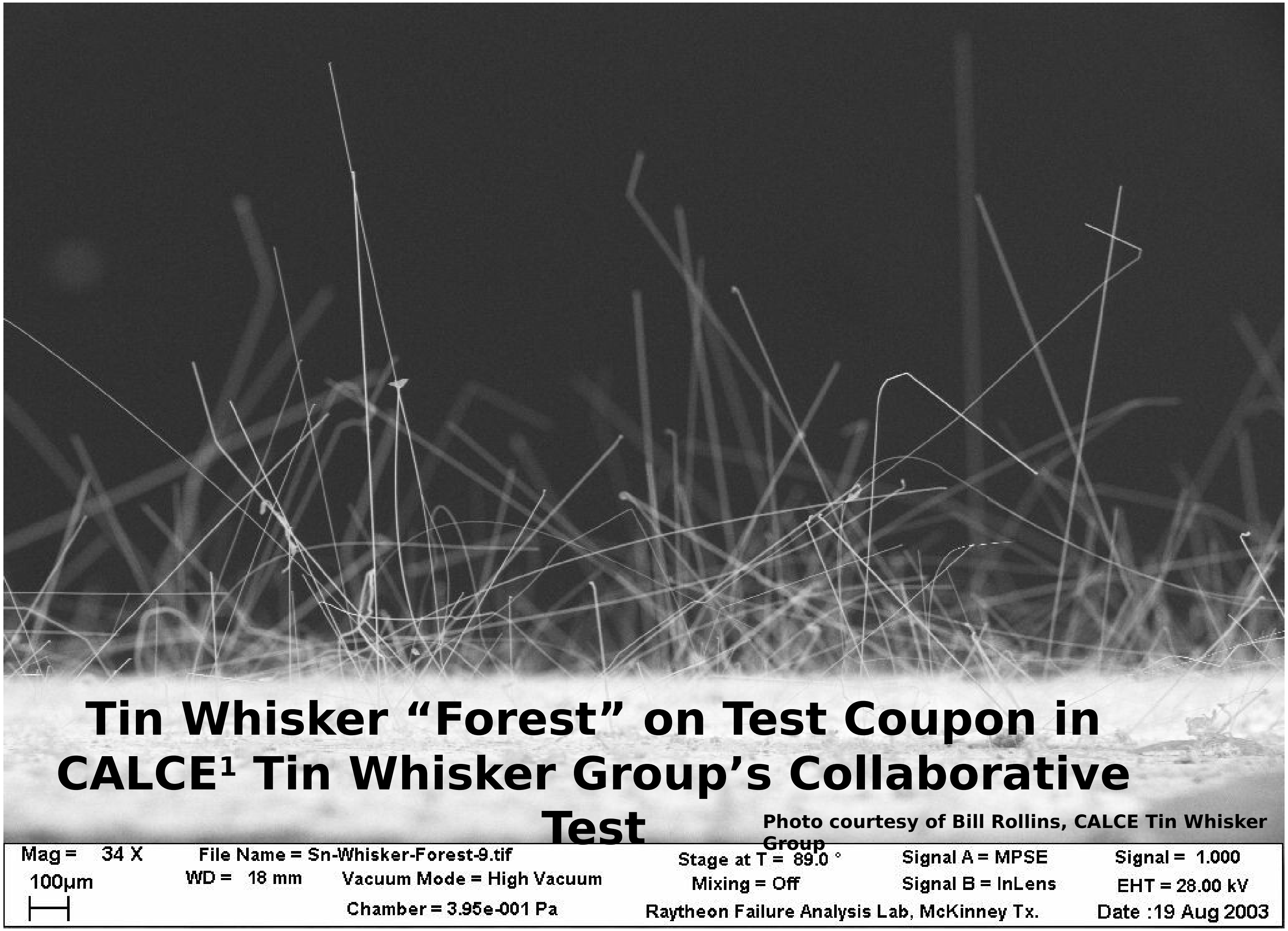


[1]

Ref: "Tin Whiskers: A History of Documented Electrical System Failures – A Briefing Prepared for the Space Shuttle Program Office," Dr. Henning Leidecker/NASA GSFC and Jay Brusse/QSS Group, Inc, April 2006

1. ATVC = Ascent Thrust Vector Control

Another Example



Tin Whisker "Forest" on Test Coupon in CALCE[1] Tin Whisker Group's Collaborative Test

Photo courtesy of Bill Rollins, CALCE Tin Whisker Group

[1]Center for Advanced Life Cycle Engineering, University of Maryland

Repair and Maintenance

- **We are the only major industry that still repairs electronics at the component level**
- **Successful repair requires knowledge of, process capability, and documentation for:**
  - Materials used in original production
  - Materials used in repair
- **Repair processes must be compatible with original production and previous repair processes**
  - Solder alloys
  - Fluxes and cleaning agents
  - Reflow profiles

What Are We Doing About It?

Industry Activities

- **Lead-free Electronics in Aerospace Project Working Group (LEAP WG)**
  - Formed in 2004 by AIA, AMC, and GEIA
  - Includes international industry and government leaders
  - Addresses primarily technical issues that are (1) unique to aerospace/military, and (2) within control of aerospace/military
  - Deliverables are military and aerospace industry consensus documents, published by GEIA (US) and IEC (international)

- **Executive Lead Free IPT**
  - Formed in 2005 by DoD
  - Includes US industry and government leaders
  - Addresses business, strategy, awareness issues
  - Deliverables are lead-free policy recommendations to government

LEAP WG *Actionable Deliverables*

Document Number	Title	Task Leader	GEIA Publication	IEC/PAS Publication
GEIA-HB-0005-1	Program Management/ Systems Engineering Management Guidelines for Managing the Transition to Lead-free Electronics	Pat Amick (Boeing)	30 June 2006	31 December 2006
GEIA-HB-0005-2	Technical Guidelines for Aerospace Electronic Systems Containing Lead-free Solder	Stephan Meschter (BAe Systems)	31 December 2006	30 June 2007
GEIA-STD-0005-1	Performance Standard for Aerospace and Military Electronic Systems Containing Lead-free Solder	Lloyd Condra (Boeing)	30 June 2006	31 December 2006
GEIA-STD-0005-2	Standard for Mitigating the Deleterious Effects of Tin in High-Reliability Electronic Systems	Anduin Touw (Boeing)	30 June 2006	31 December 2006
GEIA-STD-0005-3	Reliability Testing for Aerospace and High Performance Electronics Containing Lead-free Solder	Tony Rafanelli (Raytheon)	30 June 2007	31 December 2007
GEIA-HB-0005-3	Repair and Rework of Electronic Assemblies Containing Lead Free Solder	Tim Kalt (US Air Force)	TBD	TBD
GEIA-xx-xxxx-x	Impact of Lead Free Solder on Aerospace Electronic System Reliability and Safety Analysis	John Biel (Smiths)	TBD	TBD

(Shaded) Released documents

Draft Policy Recommendation to DoD, FAA, NASA:

3. Actions:

Each service and DLA needs to ensure that their systems and programs minimize the impacts due to the global transition to lead free. Each service and DLA shall assess and mitigate the applicable risks in order to meet their mission requirements.

The assessment could be accomplished by the development of a lead-free implementation plan for each affected program as outlined (in) the references attached below. GEIA-STD-0005-1, along with the supporting references, provides a basis by which the plan and mitigation strategy may be developed.

Program “Concerns” (GEIA-HB-0005-1)

- **Reliability**
- **Configuration Control**
- **Risk Management**
- **Tin Whiskers**
- **Rework/Repair**
- **Cost**
- **COTS Components, Assemblies, Equipment**
- **Quality**
- **Contract Language**
- **Program Constraints**
- **System Engineering Management Plan**

(More detail can be found in GEIA-HB-0005-1)

Potential Lead Free Requirement (for OEM)

(Avionics OEM supplier) shall not use electronic assembly processes, materials, or components with lead free solder alloys without approval by (customer)

Approval may be granted through:

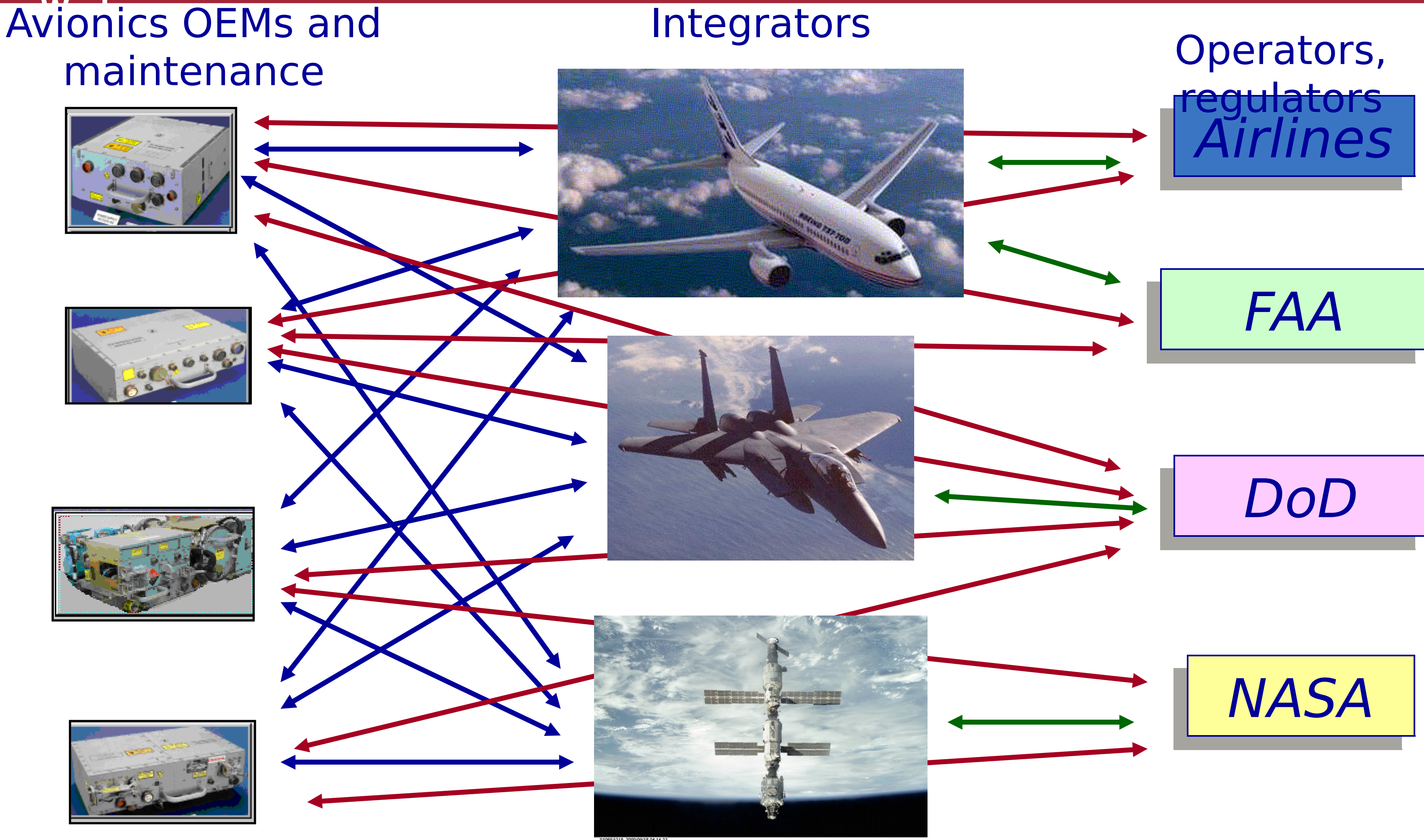
- ***Change Request for each instance of lead-free solder, or***
- ***A customer-approved Lead Free Control Plan, compliant to GEIA-STD-005-1 and GEIA-STD-005-2***

The Biggest Risk: Fragmentation

"The worst real life resolution of the lead-free solder issue is the direction in which we are now headed – multi-track electronics manufacturing leading to a logistic/supply chain/manufacturing nightmare."

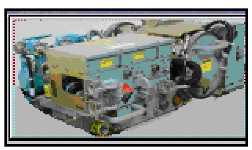
- Association Connecting Electronics Industries (IPC), 2001

The Most Expensive Way



Program-specific lead free requirements and processes

The Less Expensive Way



Each supplier has a baseline LFCP

Airlines

FAA

DoD

NASA

Common lead-free requirements and processes

The LFCP Process

Off-line (not program-specific):

Corporate-level customer requirement for LFCP, compliant to GEIA-STD-0005 -1 and -2

→

Supplier documents baseline processes in corporate-level LFCP

→

One-time LFCP approval

On-line (program-specific):

Approved LFCP is proposal or contract deliverable

→

Negotiate deviations and incremental costs for each program

→

Contract

Cost Breakdown*

Non-recurring

- **Capital equipment $0.5 - 1.0 M**
- **Process development $1.5 - 2.5 M**
- **Process documentation $1.5 - 2.5 M**
- **Training $1.0 – 3.0 M**
- **Re-qualification** *(processes, products)* **$1.0 – $10.0 M**
- **Total** *(assumed $5M in previous slide)* **$5.5 – $19.0 M**

Recurring

- **Reprocessing parts** *(industry estimate: $2-$8 per part)*
  - *Assume $2/part x 100,000 parts/airplane: $400,000/airplane*
- **Reduced yield**
- **Maintain processes, documentation, training**
- **Inventory and configuration control**

**Assumes 'mixed assembly' case for a 'generic' avionics OEM*